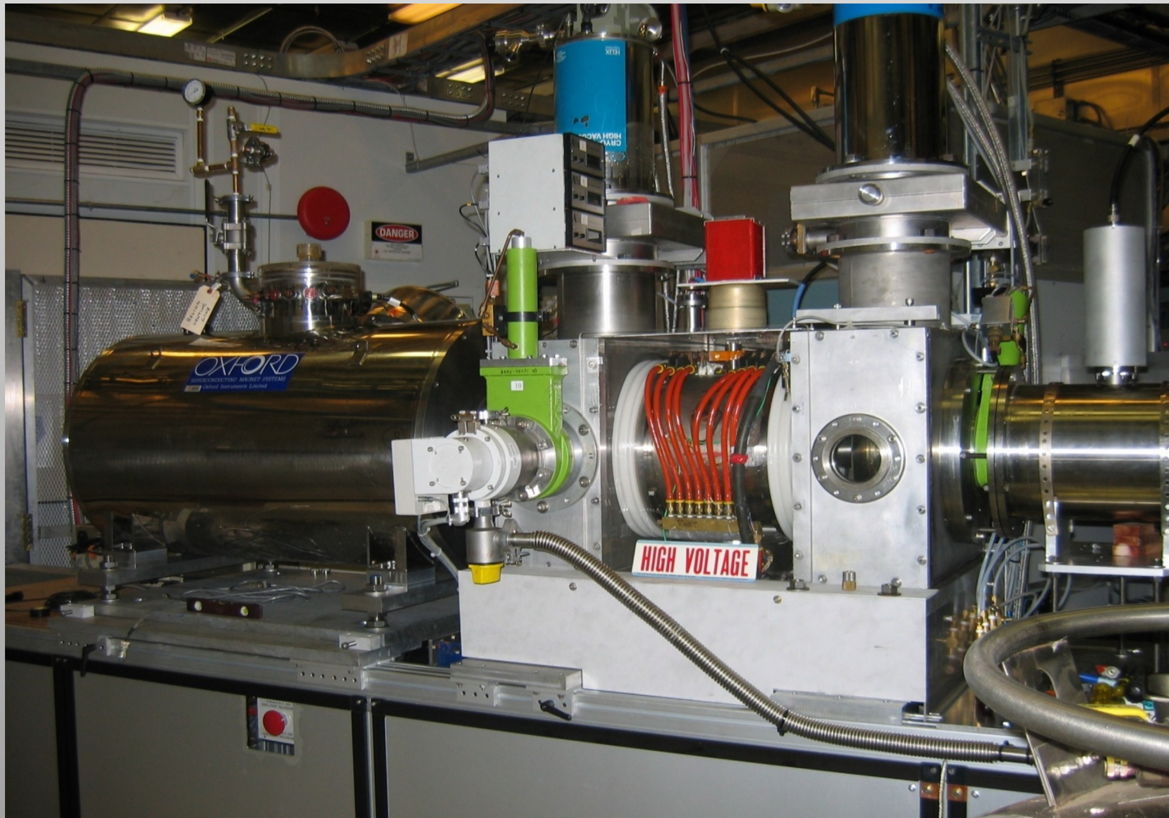
Polarized H^- Source Upgrade for RHIC

A.Zelenski

- Fast Atomic Hydrogen Source Development.
- A new “combined function” superconducting solenoid.
- Precision, absolute polarimetry development for the high intensity beam.
- Polarization studies.

MAC, November 15, 2010

RHIC operational Polarized H^- Source.



RHIC OPPIS produces reliably 0.5-1.0mA polarized H^- ion current.
Polarization at 200 MeV:
P = 80-85%.
Beam intensity (ion/pulse) routine operation:

Source	- 10^{12} H^-/pulse
Linac	- $5 \cdot 10^{11}$
AGS	- $1.5\text{-}2.0 \cdot 10^{11}$
RHIC	- $1.5 \cdot 10^{11}$ (protons/bunch).

A 29.2 GHz ECR-type source is used for primary proton beam generation.
The source was originally developed for dc operation.
A ten-fold intensity increase was demonstrated in a pulsed operation by using a very high-brightness Fast Atomic Beam Source instead of the ECR proton source .

Polarized beams at RHIC.

OPPIS

$10 \cdot 10^{11}$(maximum $40 \cdot 10^{11}$) polarized H^- /pulse.

LINAC

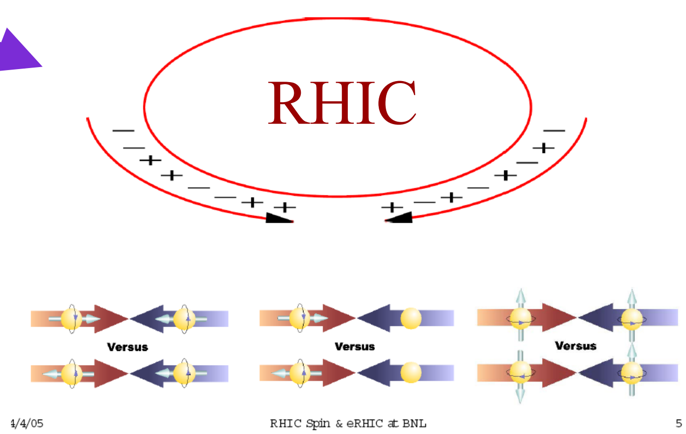
$5 \cdot 10^{11}$ polarized H^- /pulse at 200 MeV, P=85-90%

Booster

$2 \cdot 10^{11}$ protons /pulse at 2.3 GeV

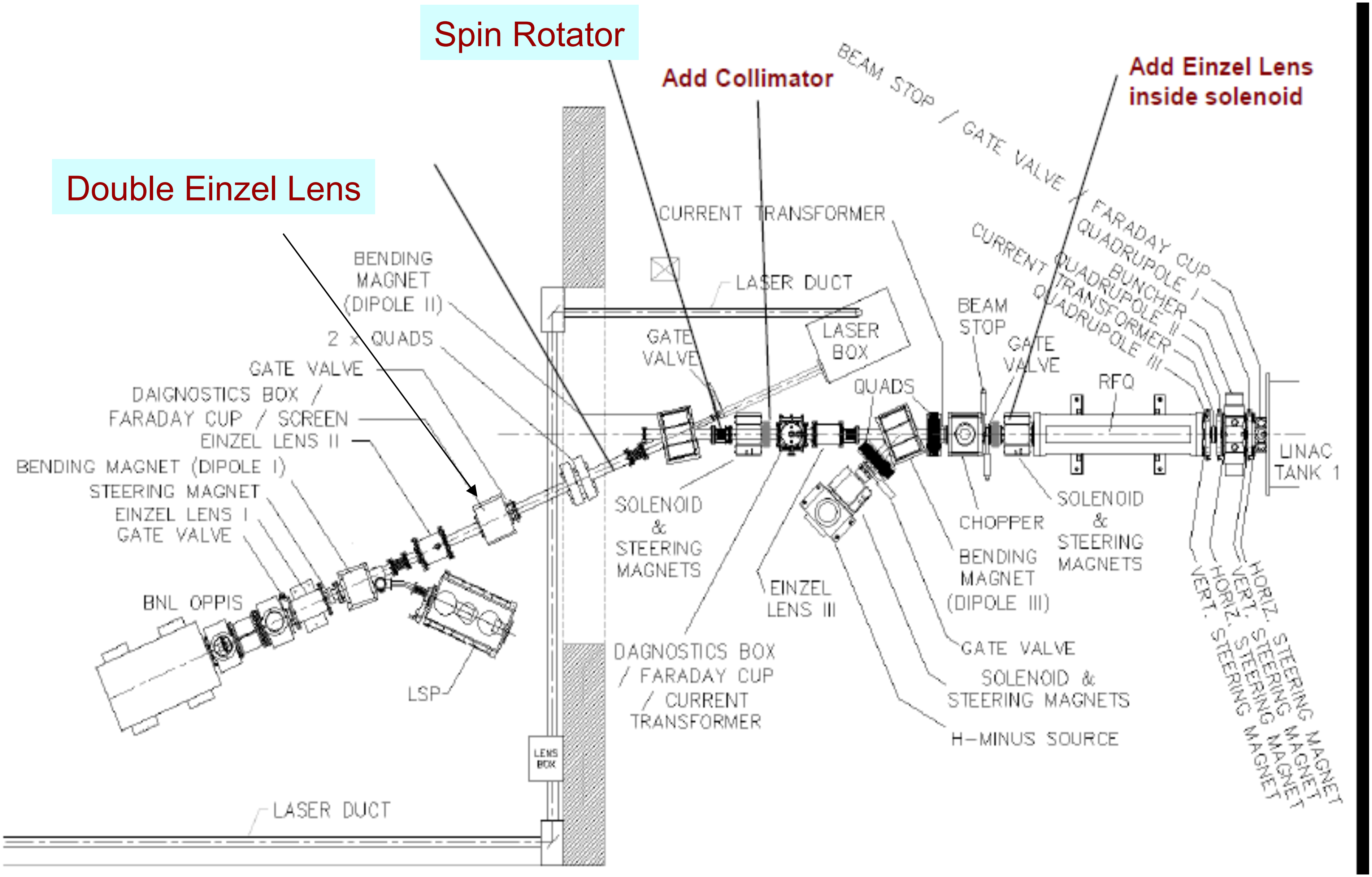
AGS

$1.7 \cdot 10^{11}$ p/bunch, P ~65%

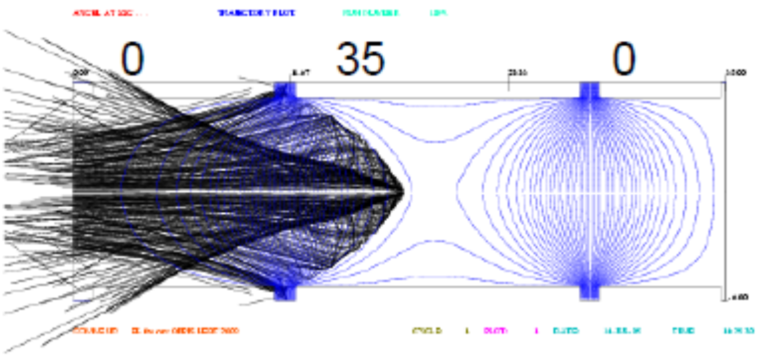


~$1.5 \cdot 10^{11}$ p/bunch, P~60-65% at 100GeV
P~41% at 250 GeV

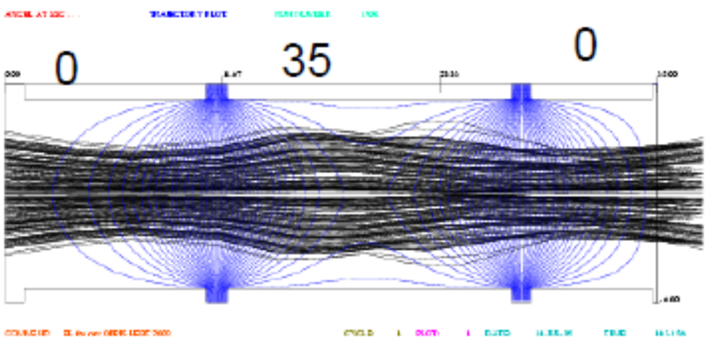
LEBT upgrades for the Run 2010



Molecular component suppression by the double Einzel lens in the LEBT.

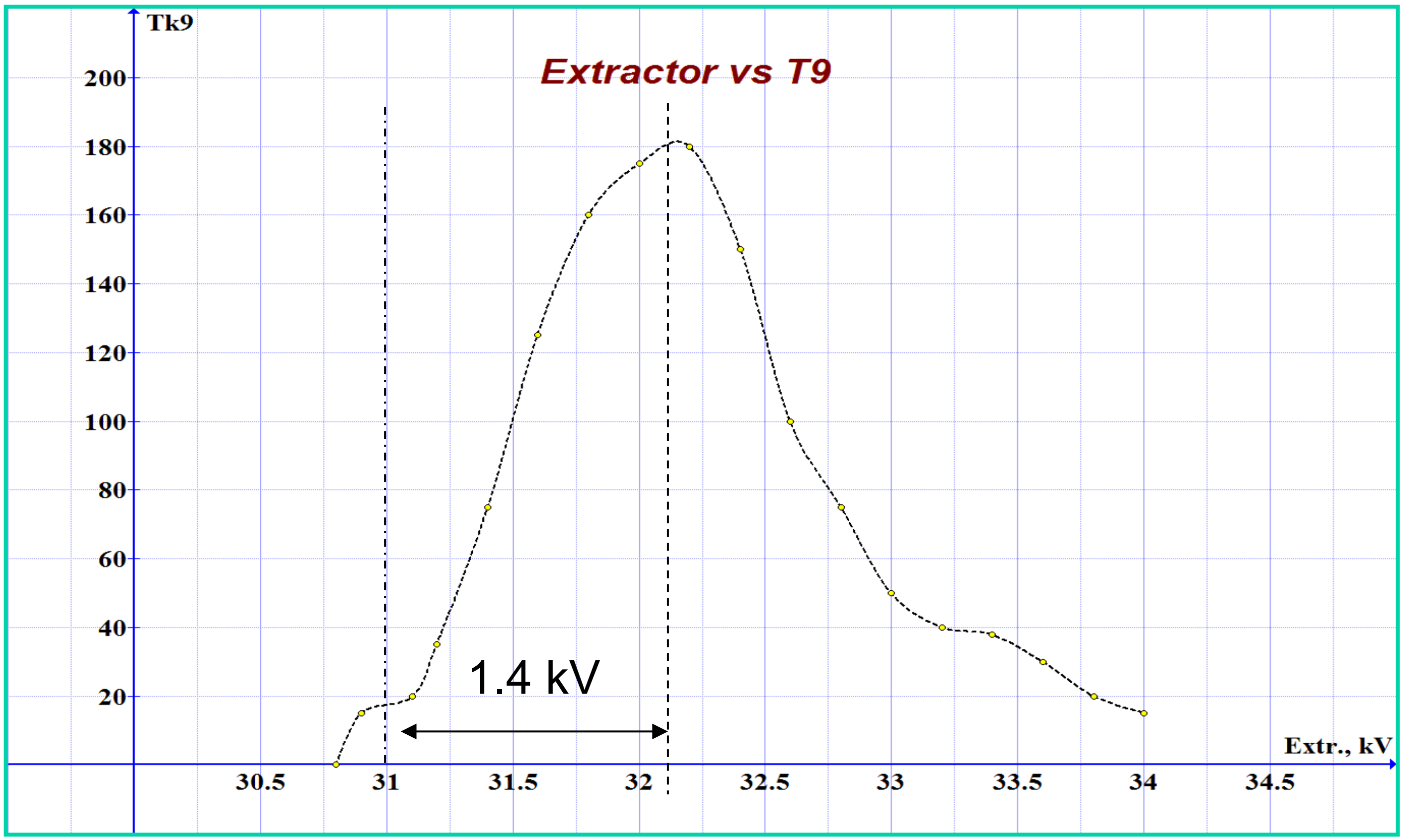


T=33.5 keV



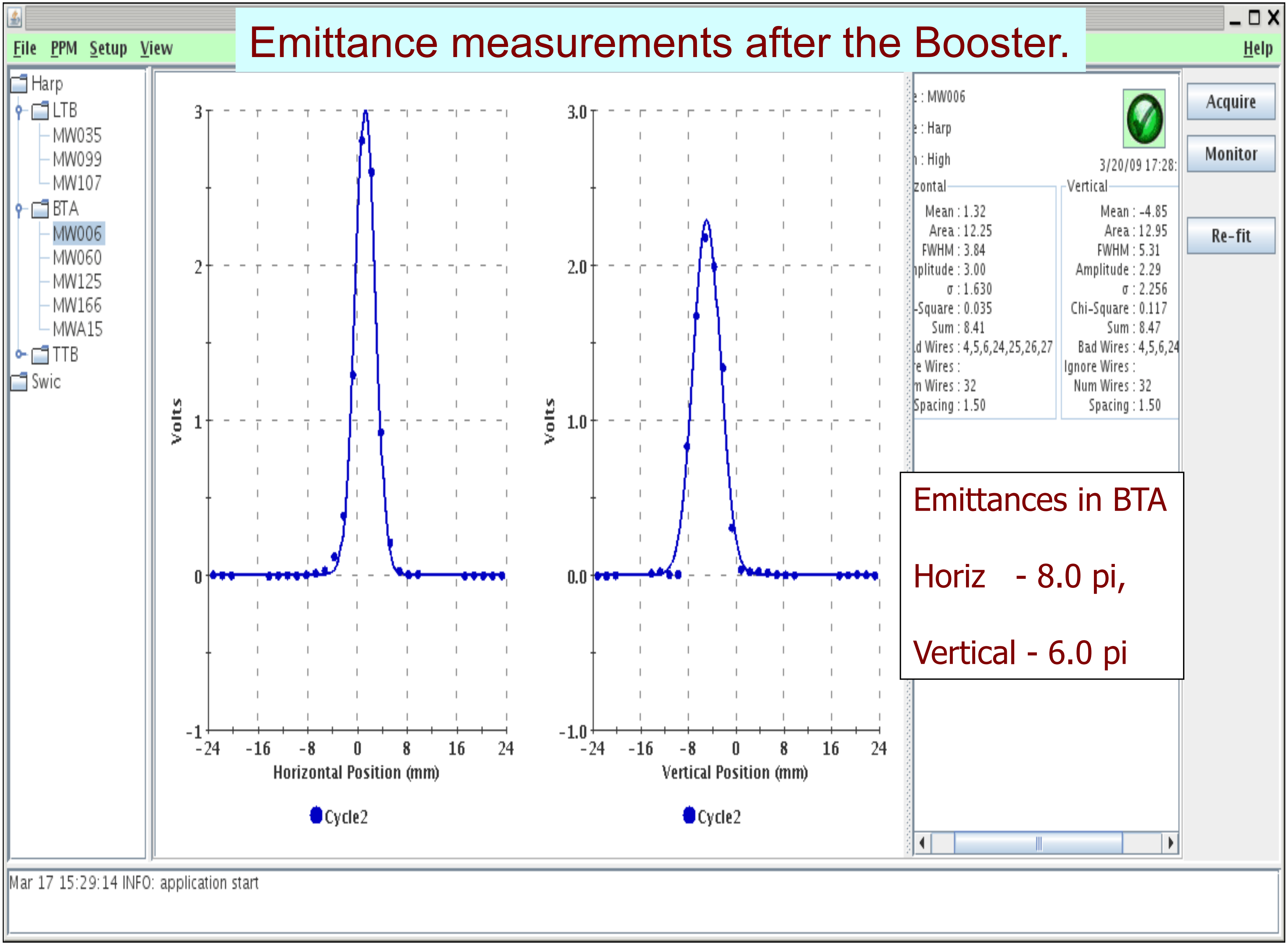
T=35.0 keV

Molecular component suppression by the double Einzel lens in the LEBT



Extractor Voltage, kV

Emittance measurements after the Booster.

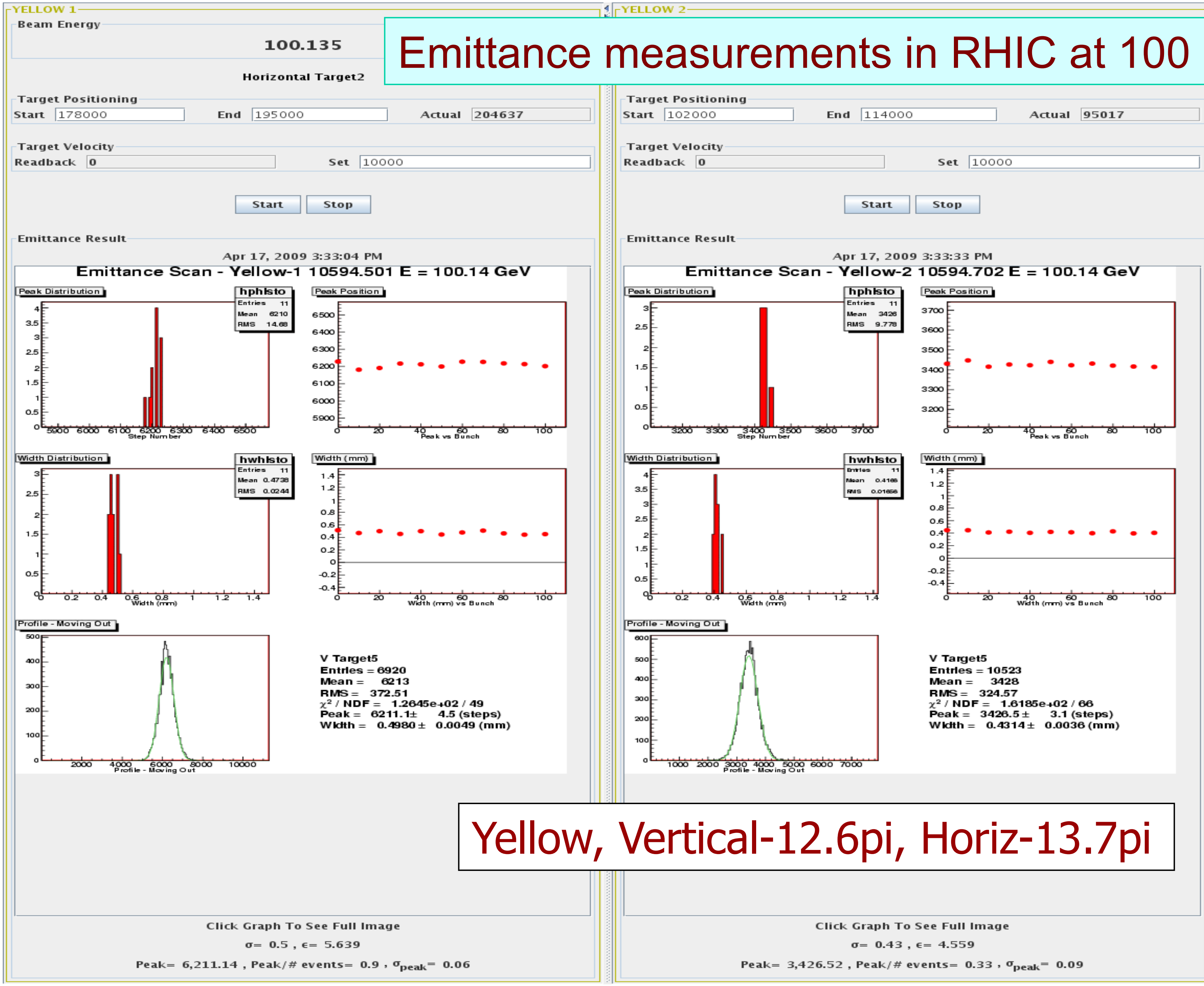


Emittances in BTA

Horiz - 8.0 pi,

Vertical - 6.0 pi

Emittance measurements in RHIC at 100 GeV

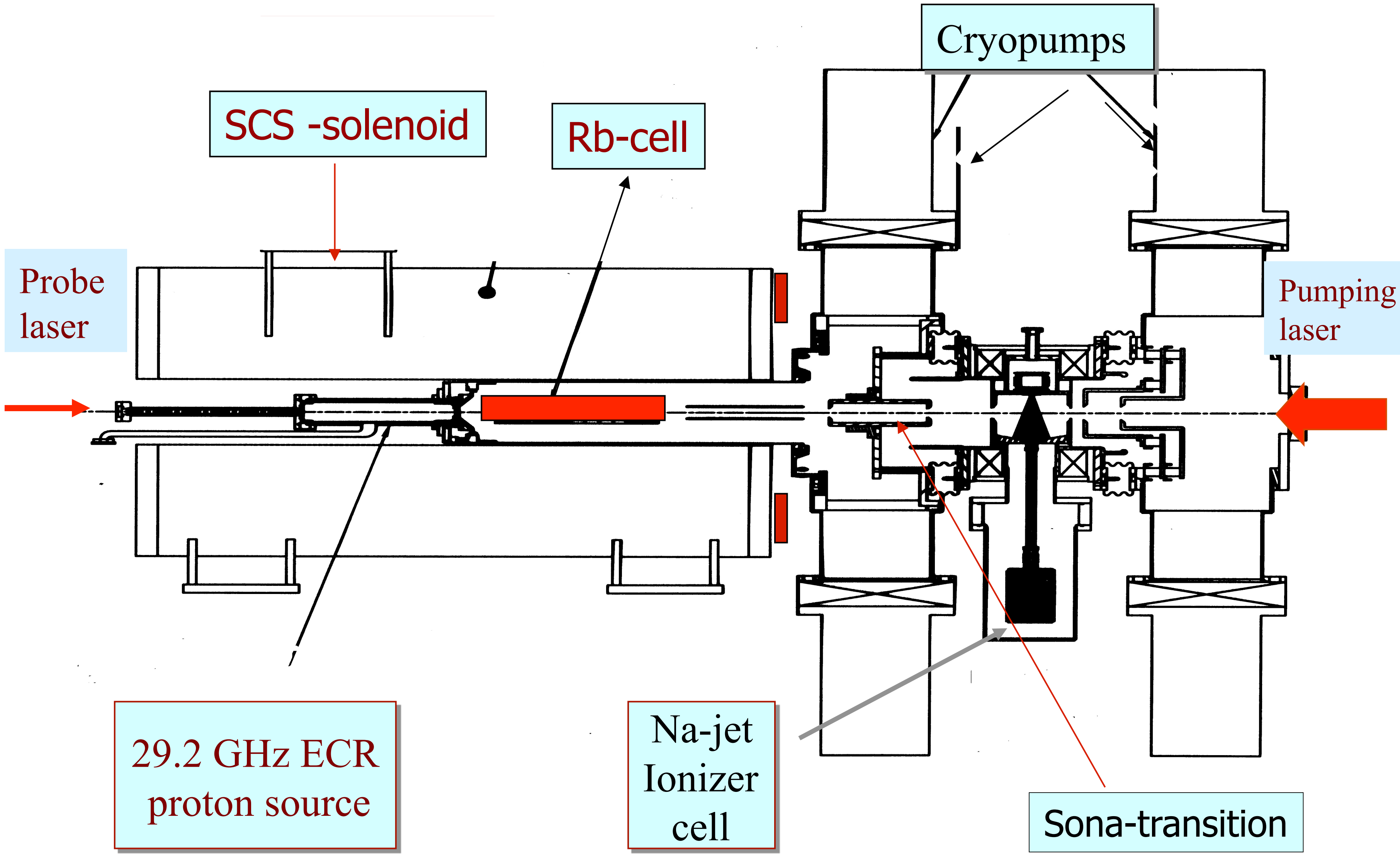


Yellow, Vertical-12.6pi, Horiz-13.7pi

Polarized H^- Source Upgrade for RHIC

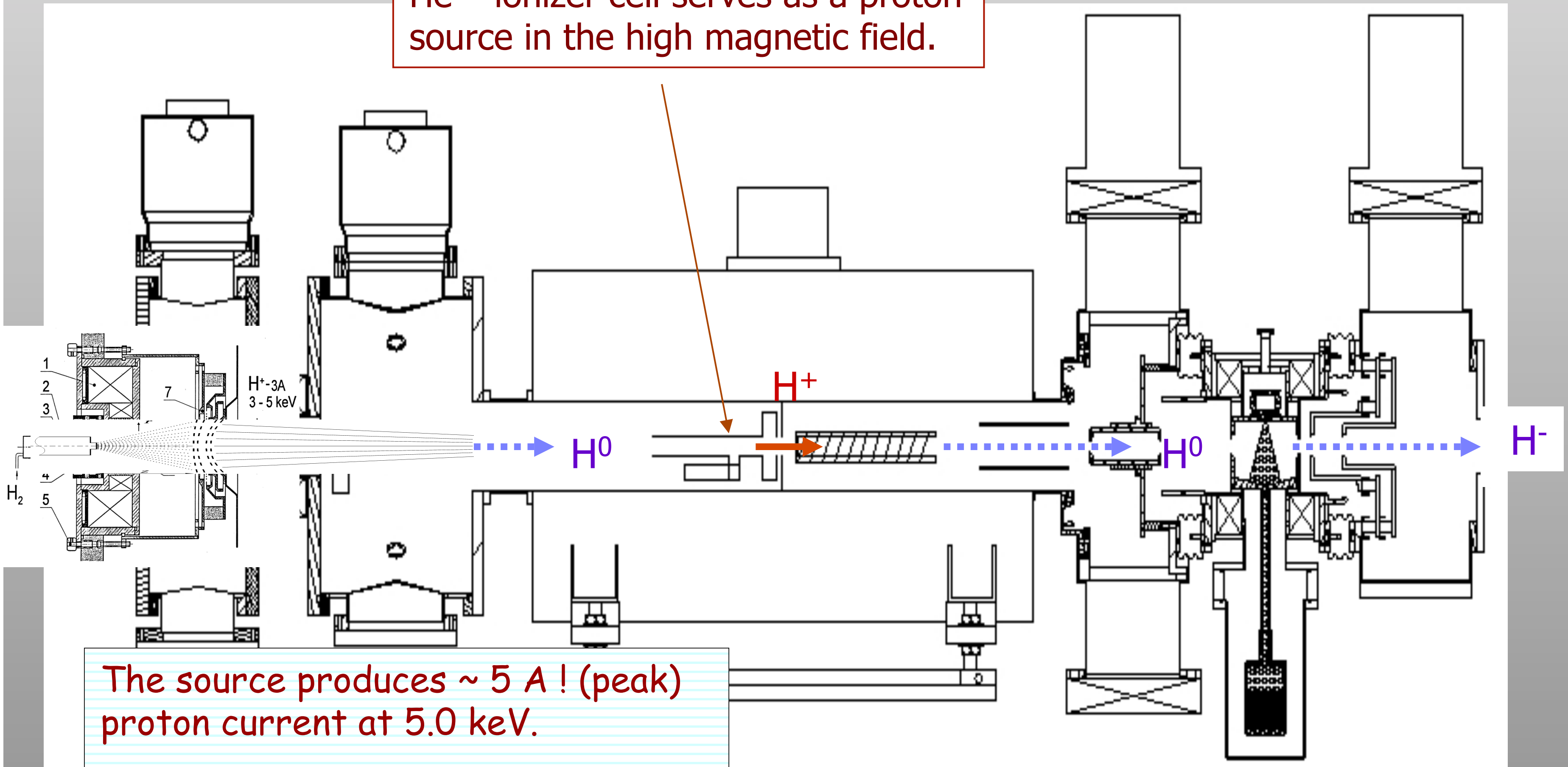
- The RHIC polarized H- ion source is being upgraded to higher intensity (5-10 mA) and polarization for use in the RHIC polarization physics program at enhanced luminosity RHIC operation.
-
- The higher beam peak intensity will allow reduction of the transverse beam emittance at injection to AGS to reduce polarization losses in AGS.
-
- There is also a plan the RHIC luminosity upgrade by using the electron beam lens to compensate the beam-beam interaction at collision points.
- It is expected also the polarization increase to 85-90%, which is a significant factor for the double spin asymmetry physics, where the figure of merit is proportional to $P^4 \cdot L$.
- This upgrade is also essential for future BNL plans for a high-luminosity electron – proton (ion) Collider eRHIC.

Schematic Layout of the RHIC OPPIS.



OPPIS upgrade with the Fast Atomic Beam Source. The third- Generation.

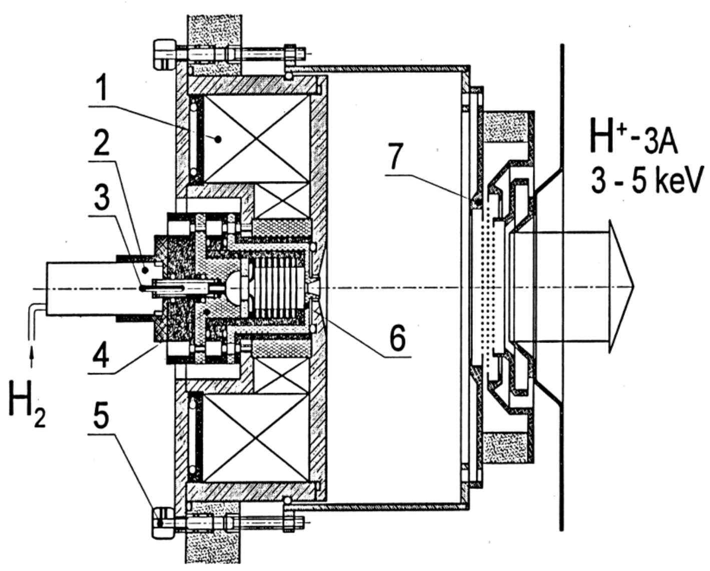
He – ionizer cell serves as a proton source in the high magnetic field.



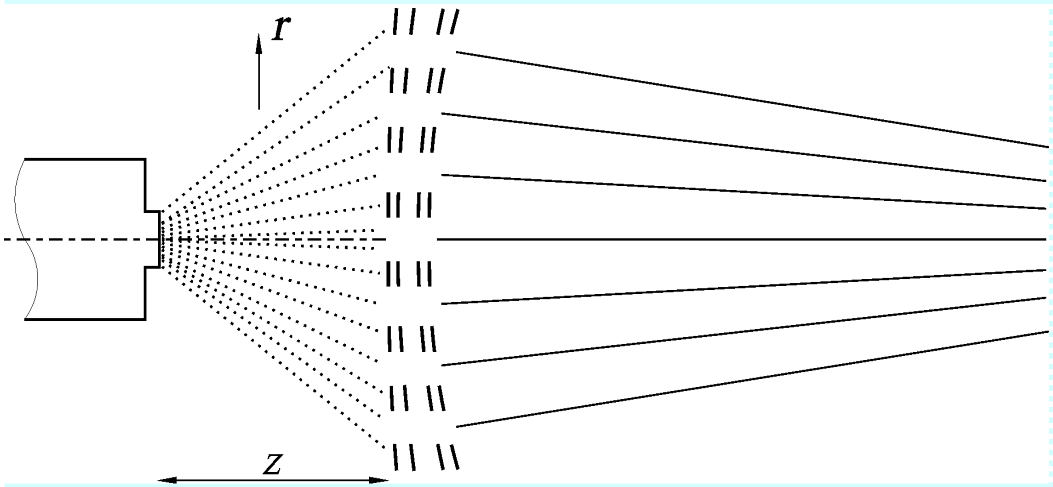
The source produces ~ 5 A ! (peak) proton current at 5.0 keV.

~ 10 mA H^- current, P = 85-90%.
~ 300 mA (high-brightness) unpolarized H^- ion current.

Proton “cannon” of the atomic H injector.



Ion Optical System with “geometrical focusing”.

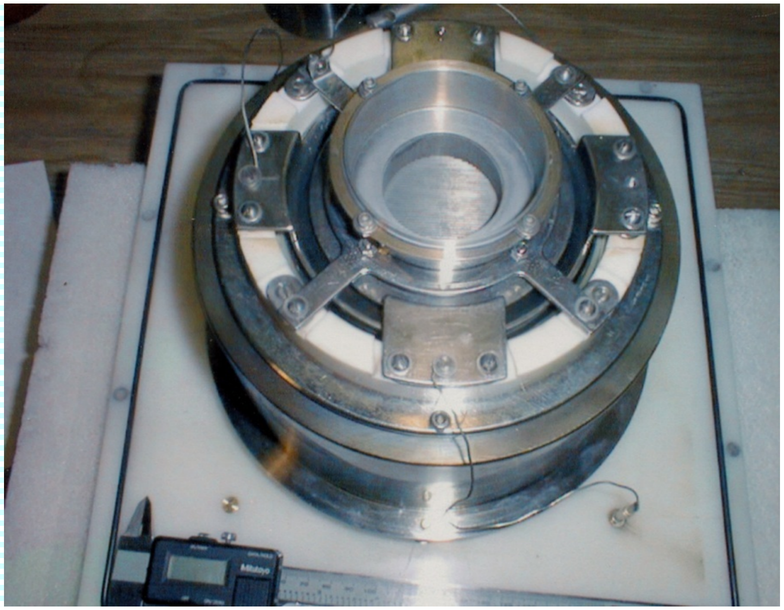


The source produced 4-5 A ! pulsed proton current at 5.0 keV.

~20 mA H^- current, P=80%

~10 mA H- current, P=85-90%.

~ 300 mA unpolarized H^- ion current.



The Atomic Hydrogen Injector.

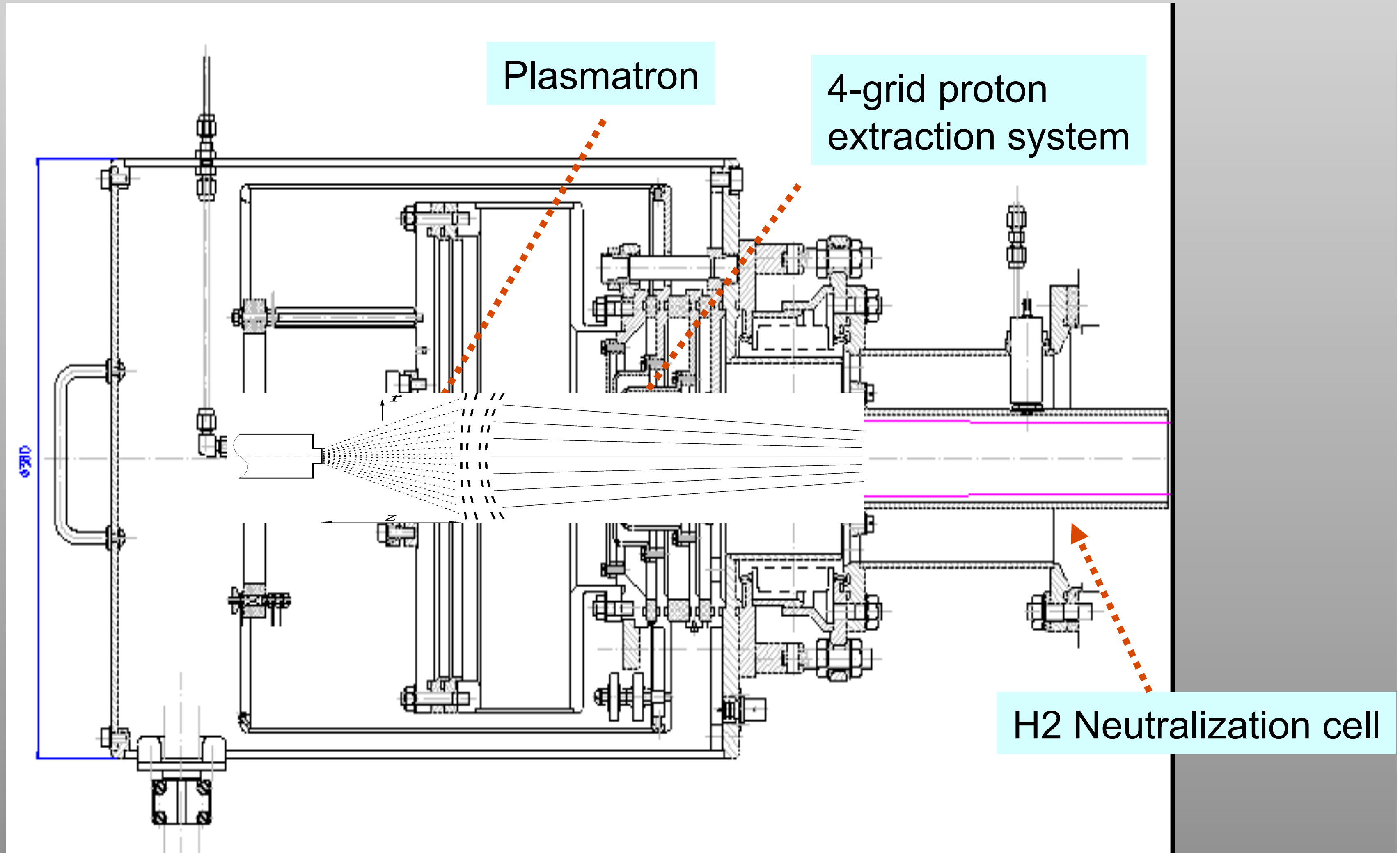
Collaboration agreement with BINP, Novosibirsk

on polarized source upgrade.

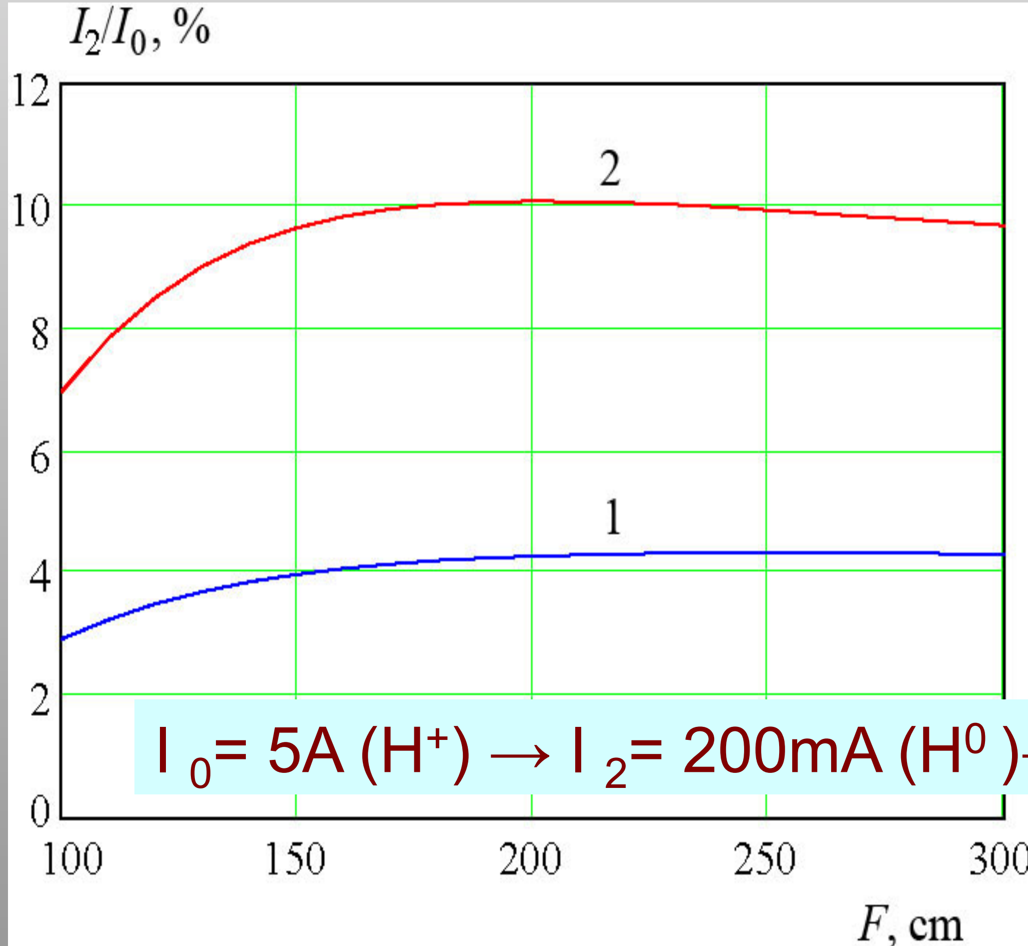
BINP physicists are doing the simulations and are involved in the experiments at the FABS test-bench.

- Contract with BINP, Novosibirsk. Delivery: March, 2011.
- Two sets of sources and power supplies, local control system.
- 4- sets of spherical extraction grids (focal length ~150 cm) for polarized source.
- 2- sets of shorter focal length (~ 50cm) grids for studies of basic limitation of high-brightness H^- ion beam production in the charge-exchange process.
- Vacuum system upgrade with TMP for He-cell pumping.

BINP design for the "Atomic Beam Injector".



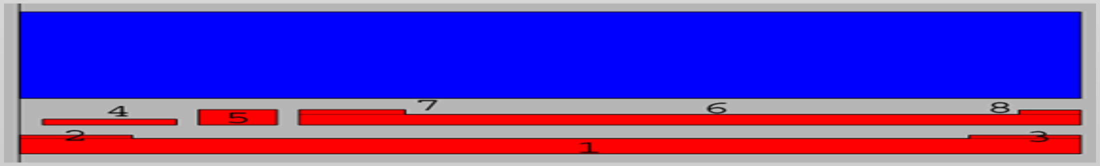
Ratio of the target current to the emitter current vs focal distance.

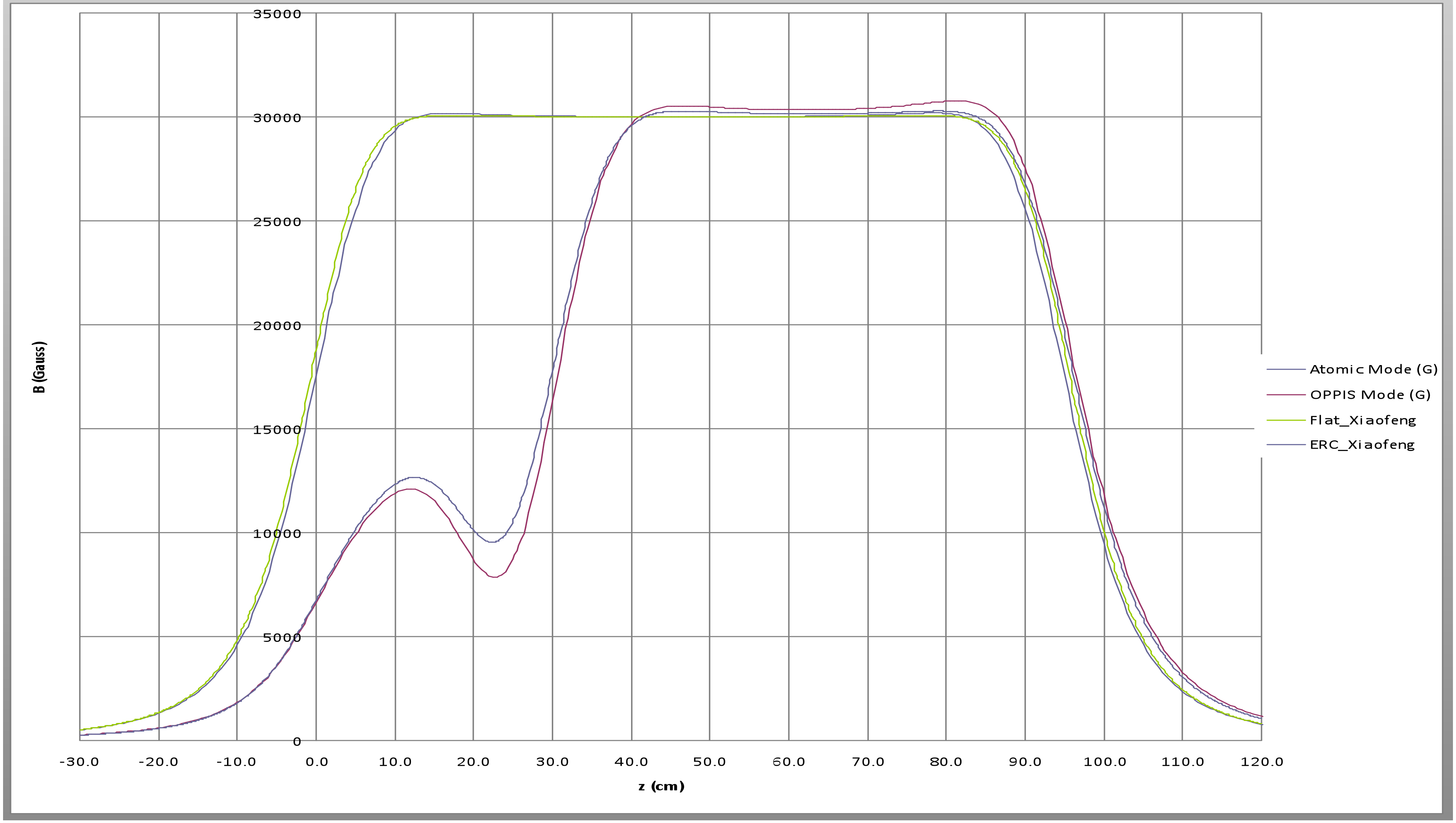


$I_0 = 5A\ (H^+) \rightarrow I_2 = 200mA\ (H^0) \rightarrow 16\ mA\ (H^-)$

Fig. 8. Ratio of the target current to the emitter current vs focal distance: 1 – without magnetic field, 2 – with magnetic field.

A new superconducting solenoid. ECR-mode.



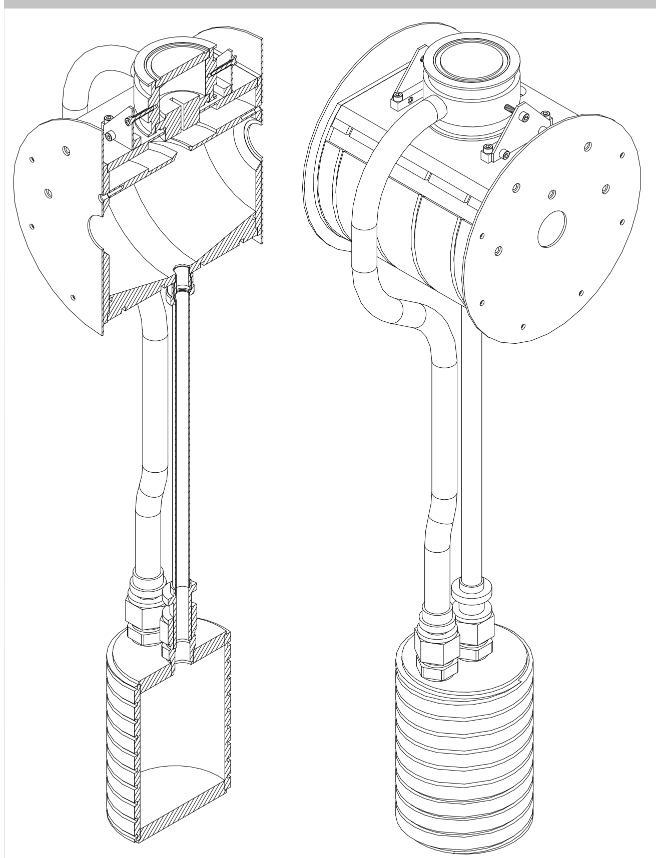


Small diameter beam in the FABS.

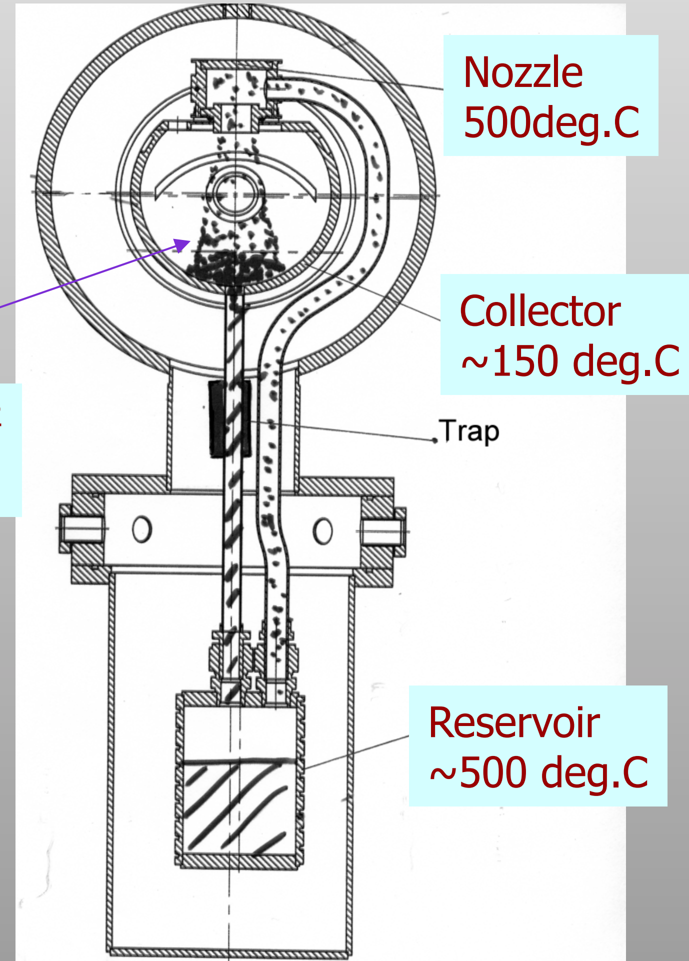
- Atomic H injector produces an order of magnitude higher brightness beam. A 5-10 mA H^- ion current can be obtained with the smaller, (about 15 mm in diameter) beam.
- Higher Sona-transition efficiency for the smaller beam radius.
- Smaller beam emittance : $\varepsilon \sim B \times R^2$
- High-brightness source (FABS) will deliver at least
  10 times more beam intensity then ECR-proton source within the small ionizer aperture.

Sodium-jet ionizer cell.

Transversal vapor flow in the N-jet cell.
Reduces sodium vapor losses for 3-4 orders of magnitude, which allow the cell aperture increase up to 3.0 cm .

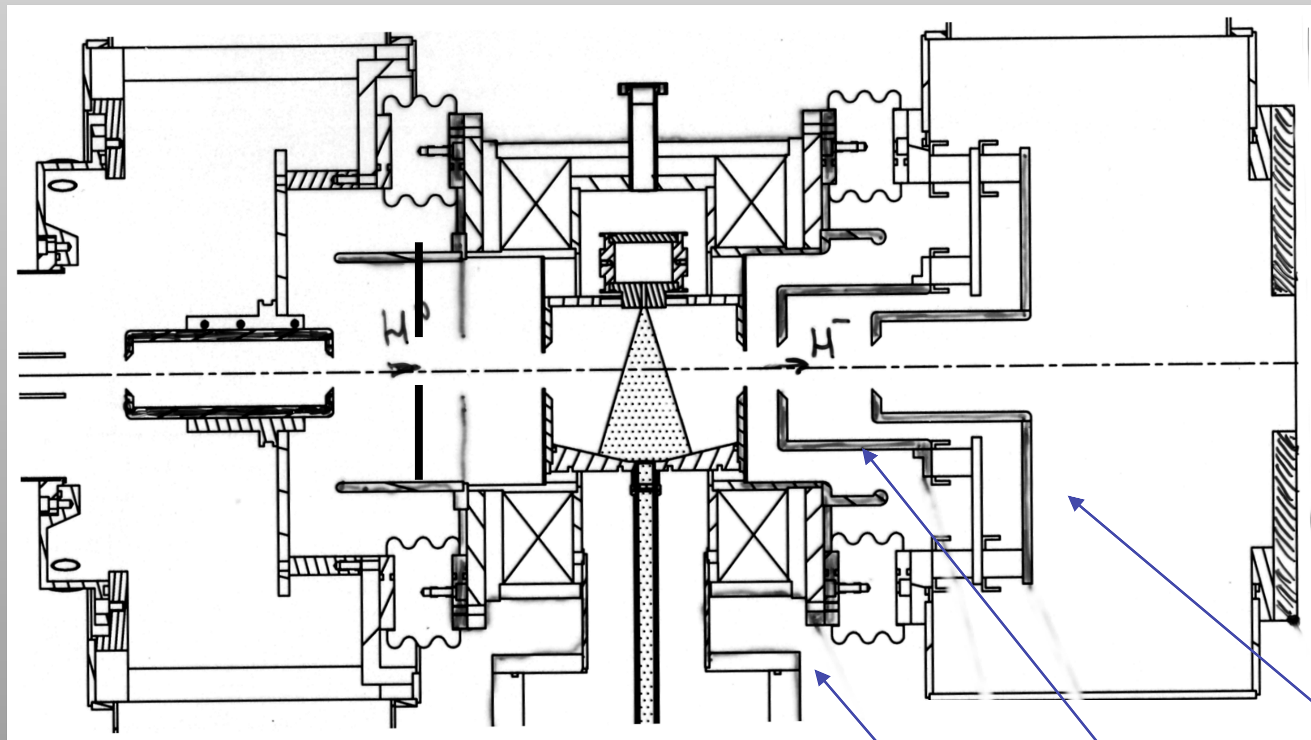


NL ~$2 \cdot 10^{15}$ atoms/cm^2
L ~ 2-3 cm



Reservoir– operational temperature. Tres. ~500 ^{o}C.
Nozzle – Tn ~500 ^{o}C.
Collector- Na-vapor condensation: Tcoll.~120^{o}C
Trap- return line. T ~ 120 – 180 ^{o}C.

H^- beam acceleration to 35 keV at the exit of Na-jet ionizer cell.



$\overrightarrow{H^-}$

35 keV

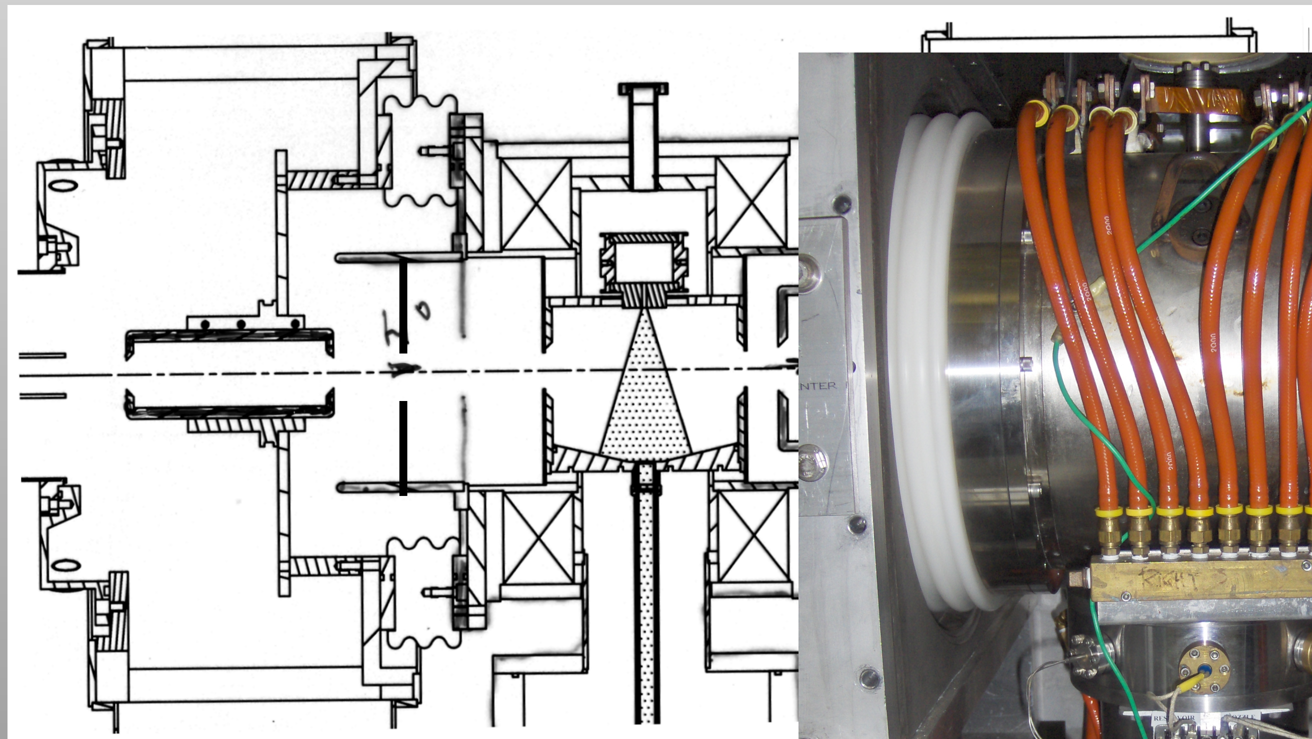
-32 kV

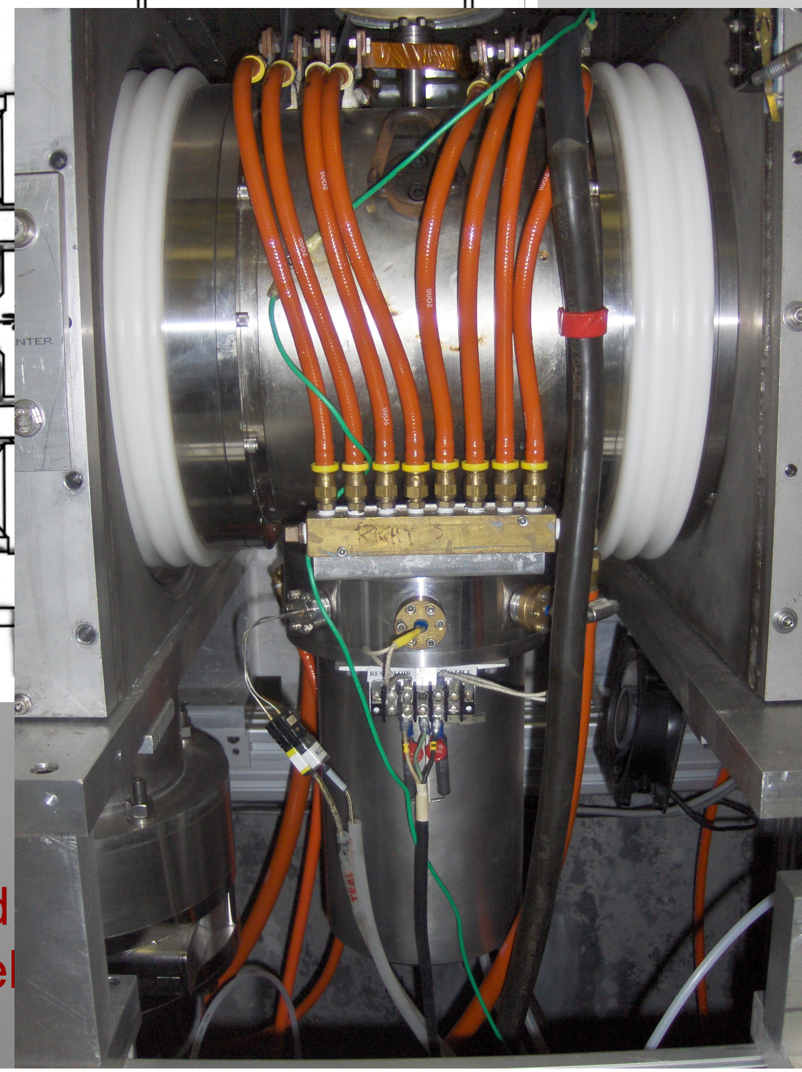
-28 keV

-15 keV

Na-jet cell is isolated and biased to – 32 keV. The H^- beam is accelerated in a two-stage acceleration system.

H^- beam acceleration to 35 keV at the exit of Na-jet ionizer cell.

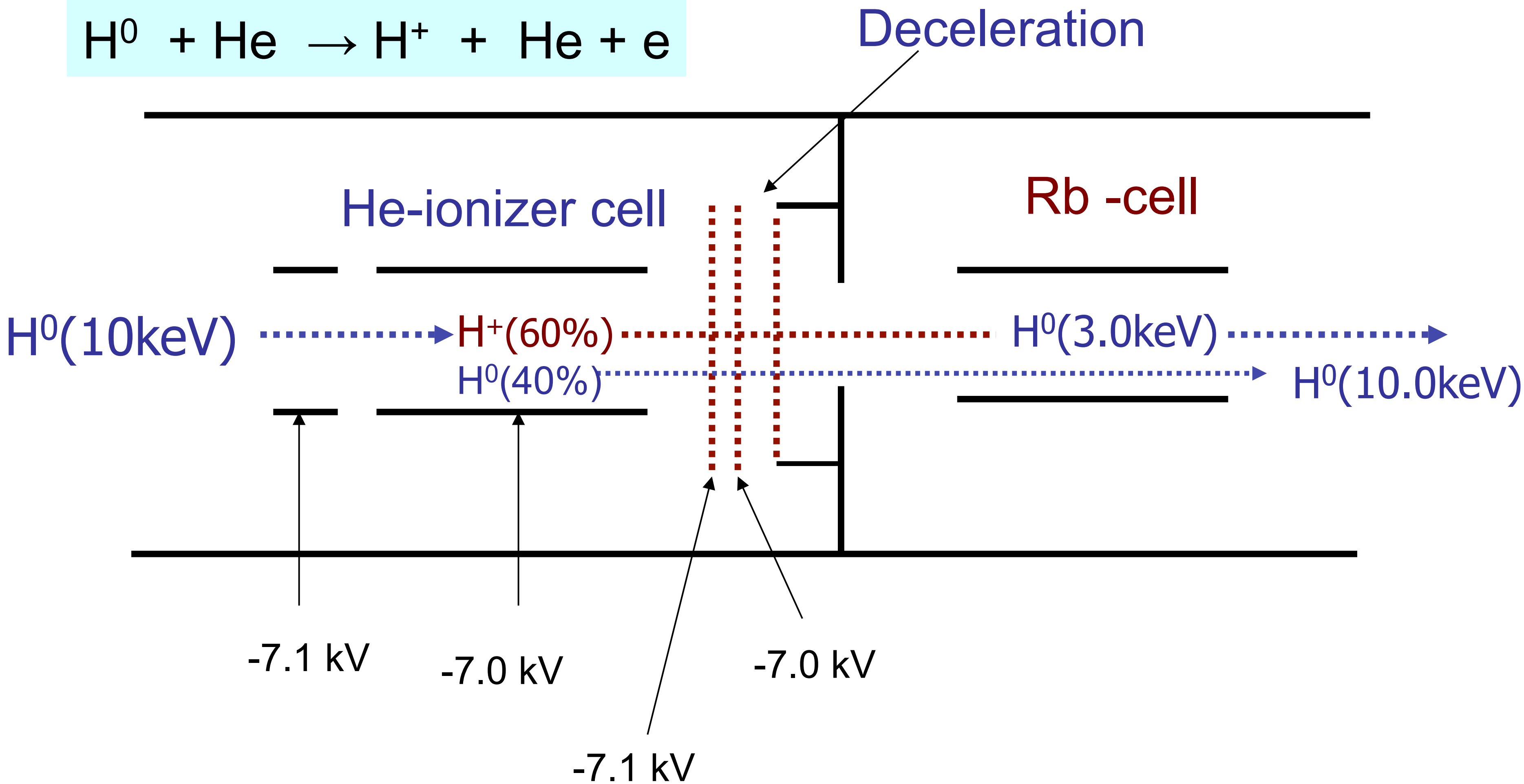




Na-jet cell is isolated and biased
accelerated in a two-stage accel

Residual unpolarized H^0 beam component suppression by the energy separation.

$H^0 + He \rightarrow H^+ + He + e$



Primary proton beam energy (~10.0 keV) choice.

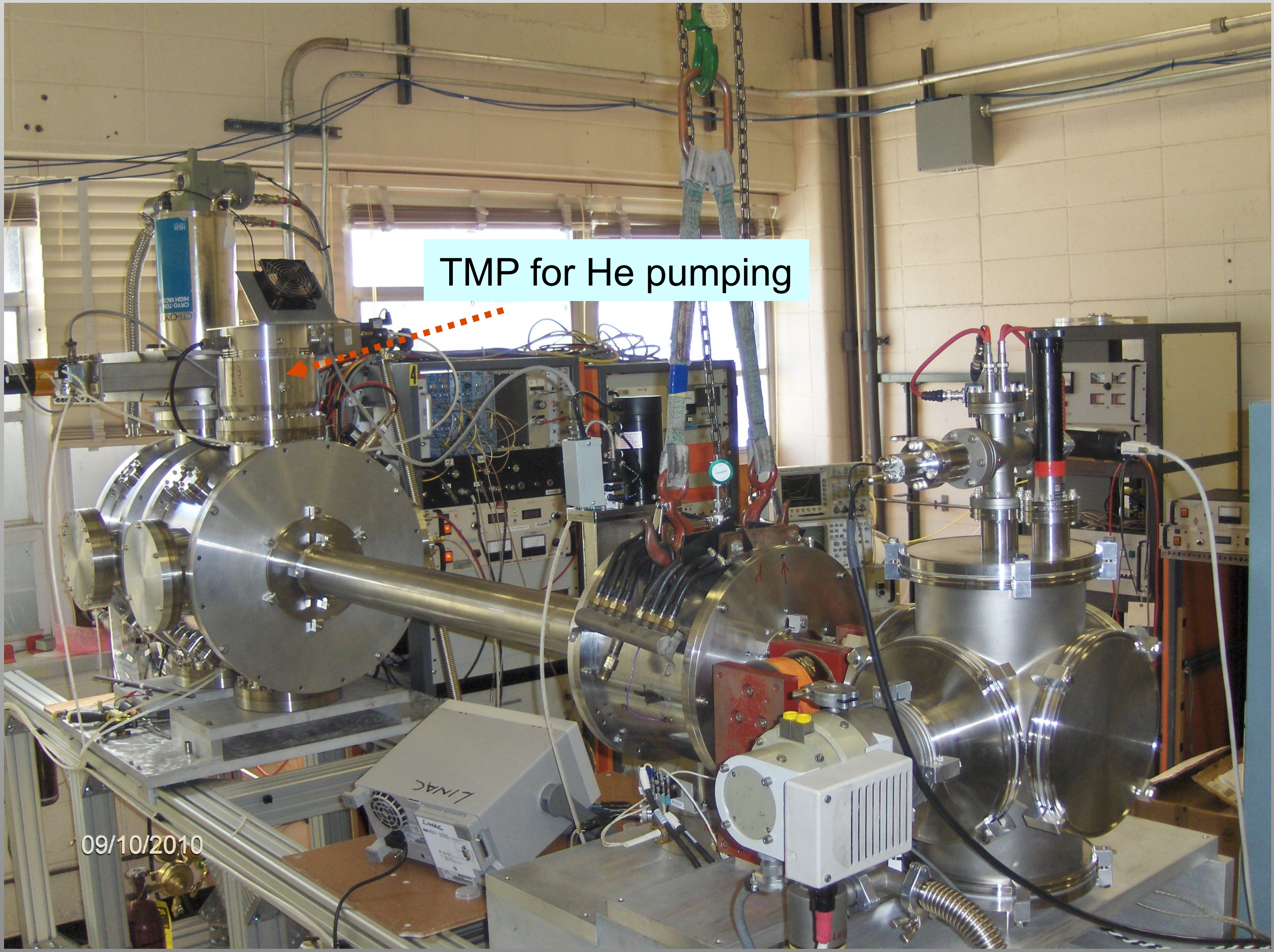
- Higher energy gives higher beam intensity.

- Lower ionization efficiency in the He-cell (~60%).

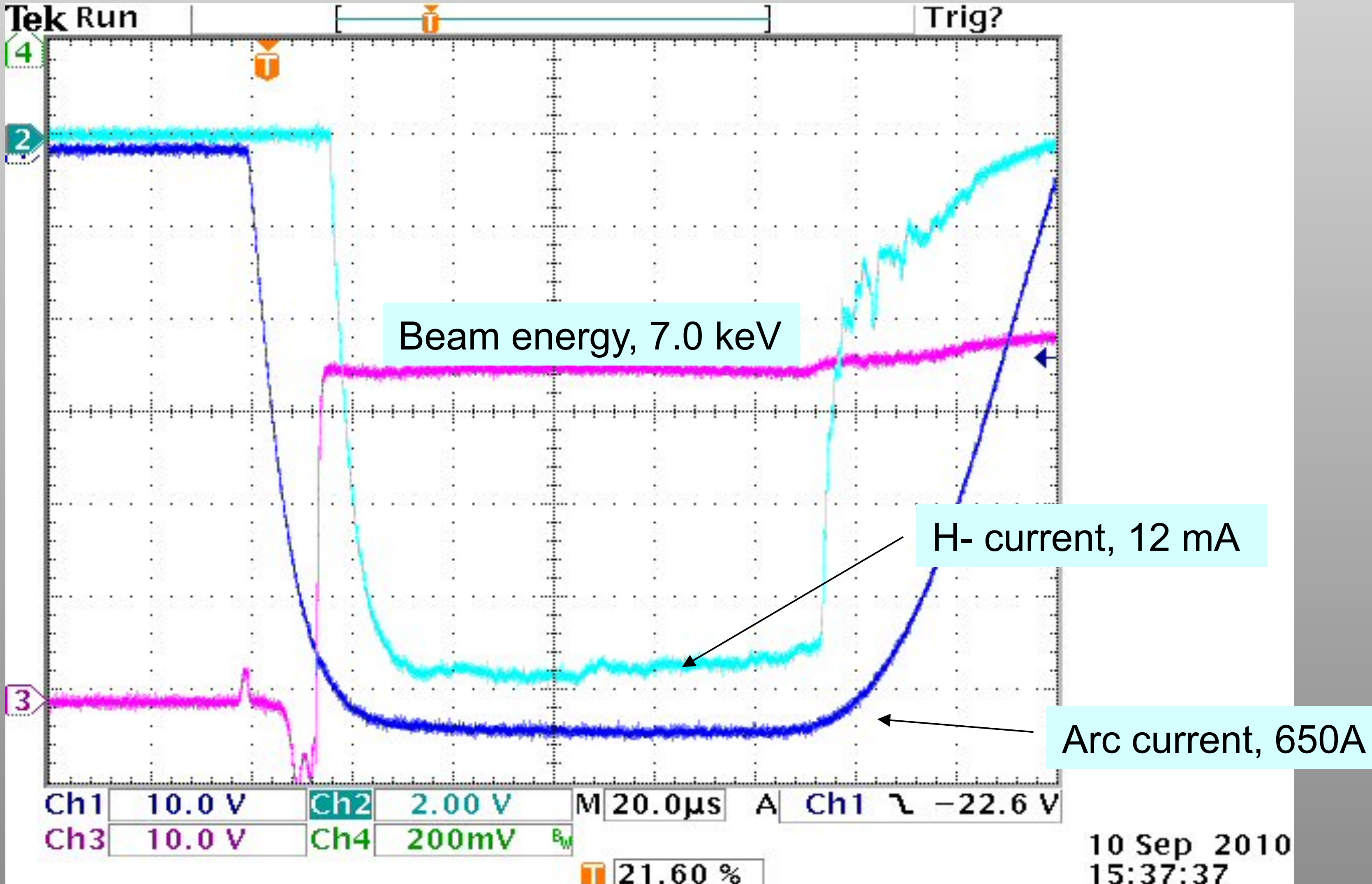
- Larger deceleration (~7.0 keV) after the He-cell is required.
-
- H^- yield reduction for 10 keV residual unpolarized H_0.

- Higher energy increases the energy separation efficiency.
- At least 10 keV energy is required for molecular H_2^+ beam component suppression.

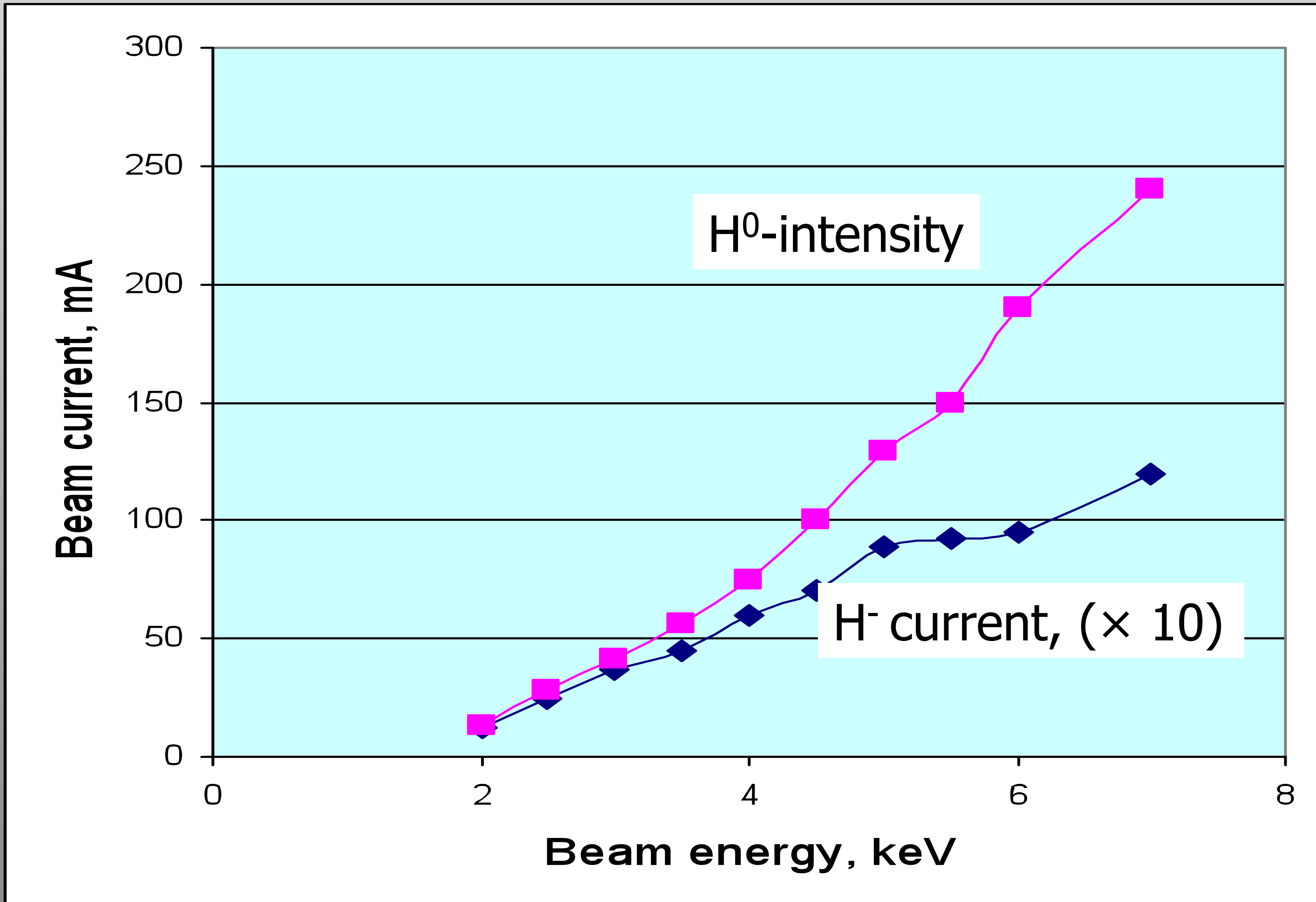
A new FABS test bench.



FABS operation.



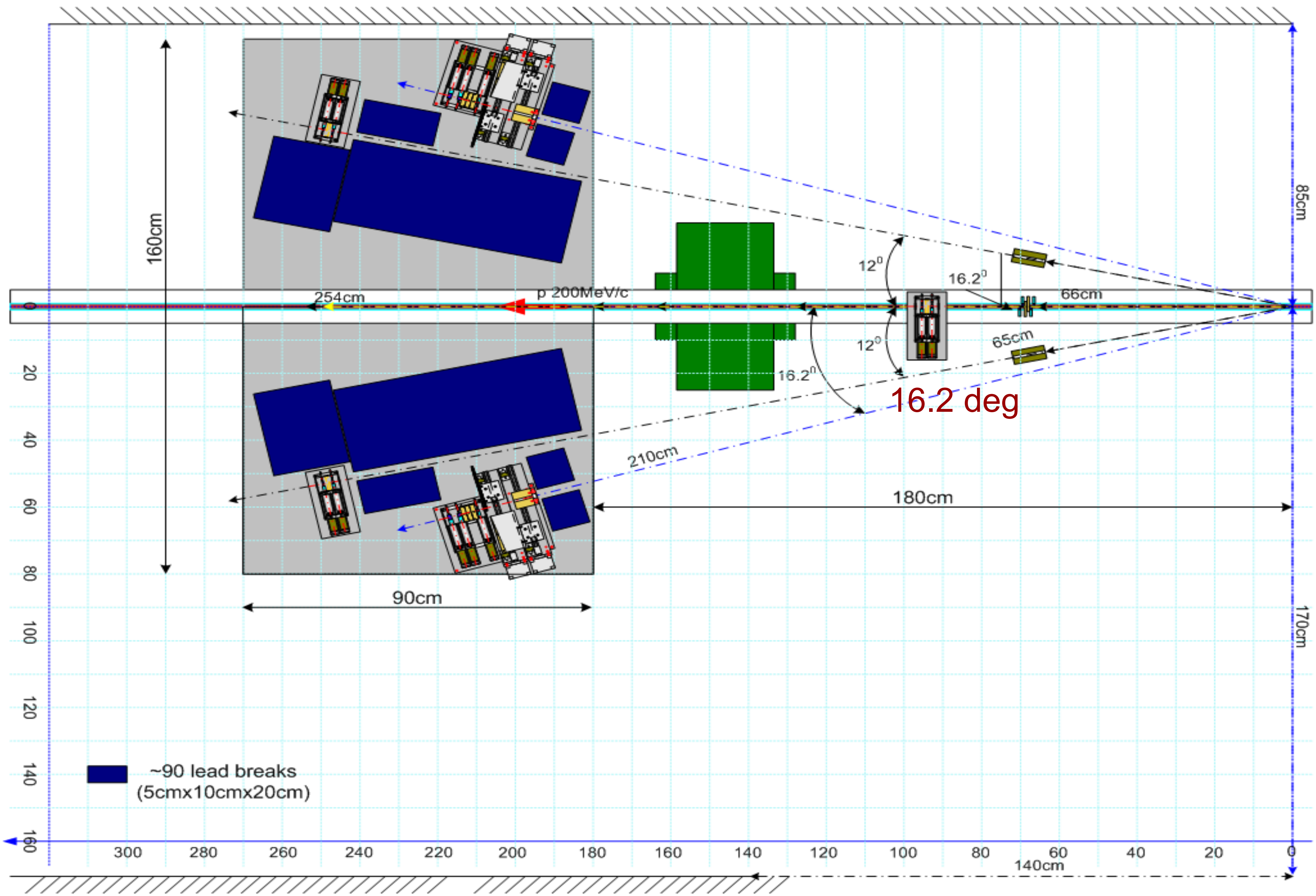
H^- ion beam current vs beam energy (within 25 mm ionizer acceptance).



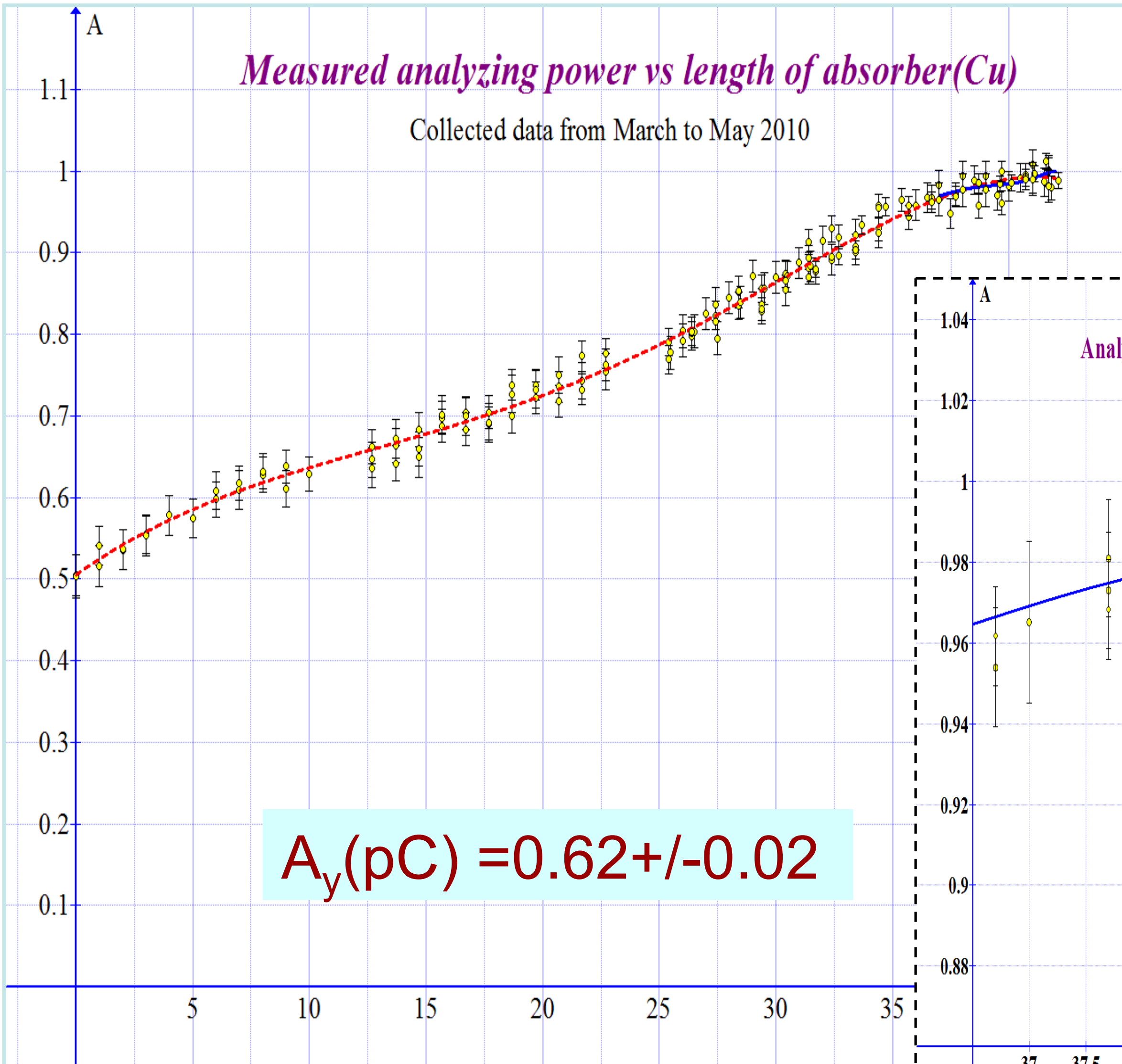
Polarimetry.

- Faraday rotation Rb polarimeter.
- Lamb-shift polarimeter for polarization measurements at the beam energies 3-35keV.
- 200MeV polarimeter upgrade.
  Precision, absolute polarization measurements at 200 MeV beam energy.

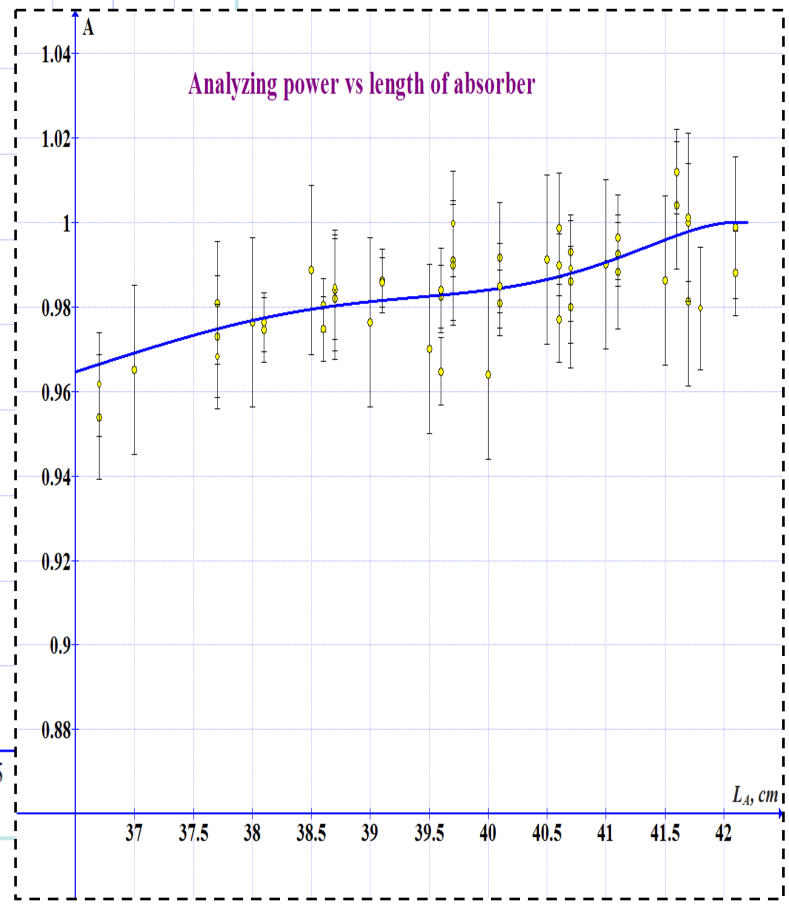
Layout of the 200 MeV proton polarimeter, (2010)



Measured Analyzing Power vs length of absorber.



$A_y(pC) = 0.62 +/- 0.02$



Polarimeter upgrade summary.

1. Elastic proton-Carbon scattering (at 16.2 deg. angle) is used in a new polarimeter setup. Analyzing power at 200 MeV is 99.35%.
2. The elastic scattering is used for calibration of inclusive 12 deg. polarimeter arm:

   A_y (pC) =0.620+/-0.005 (preliminary).

3. Rate in 16 deg arms is ~ 10 event/pulse (12 deg ~300);
4. Ratio N(Sc1^Sc2)/N(Sc1^Sc3) is used for the beam energy monitoring.

Summary

- Atomic H injector produces an order of magnitude higher brightness beam.
- A 5-10 mA H^- ion current can be obtained with the smaller diameter beam.
- This reduces polarization losses and produce smaller emittance polarized beam. Neutralization in the residual gas is much smaller too.
- All these factors combined will increase polarization to 85-90%.

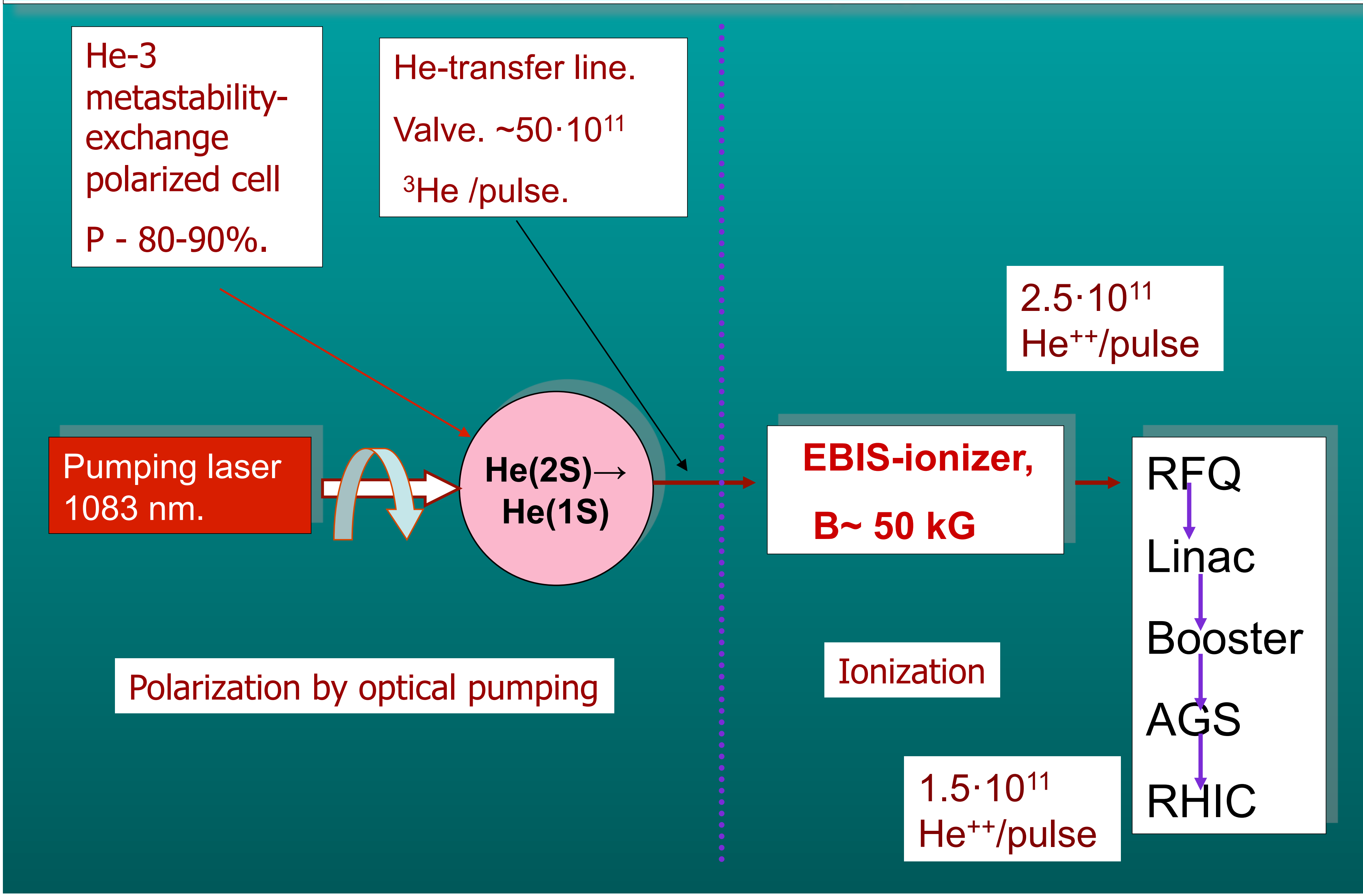
Polarized $^3He^{++}$ beam in RHIC.

- Polarized $^3He^{++}$ source:
- Ionization of ^3He polarized by optical pumping and metastability–exchange technique in EBIS.
  EBIS had been commissioned th Septrember.
  Polarized ^3He in collaboration with MIT Bates, R.Milner (DOE grant).

- $^3He^{++}$ ion beam acceleration. (W.McKay presentation).

- Polarimetry. Lamb-shift polarimeter. 2 MeV polarimeter.
- CNI polarimetry in AGS and RHIC.
- Polarimeter calibration.

EBIS ionizer for polarized ^{3}He gas.
(J.Alessi, A.Zelenski -proposal).



EBIS ionizer for polarized ^3He gas.

- Polarized ^3He gas is produced by a "metastability exchange" technique. P ~ 80-90% (pressure ~ 1 torr).
- ^3He gas is injected in the EBIS ionizer.
- The ionization in EBIS is produced in a 50 kG field.
- This field will greatly suppress the depolarization in the intermediate He^+ single charge state, $B_c(He^+)$ = 3.1 kG
- The charge ratio $He^{++}/He^+ >> 1$.
- The number of He^{++} ions is limited to the maximum charge which can be confined in EBIS (about $2.5 \cdot 10^{11}$ of $^3He^{++}$/ store).
- It is sufficient to obtain ~10^{11} He^{++}/bunch in RHIC.

(Zelenski)

Nuclear polarization of the ^{3}He by optical-pumping and metastability-exchange technique.

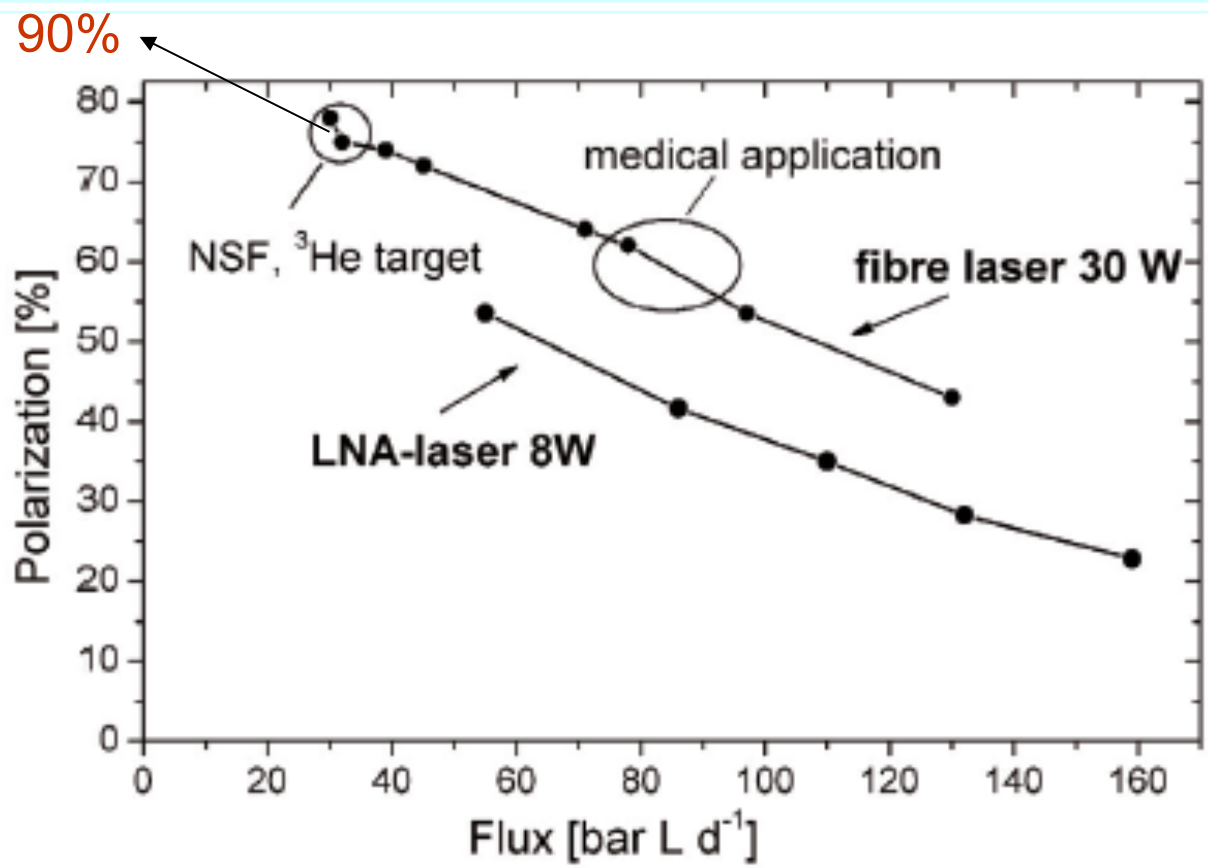
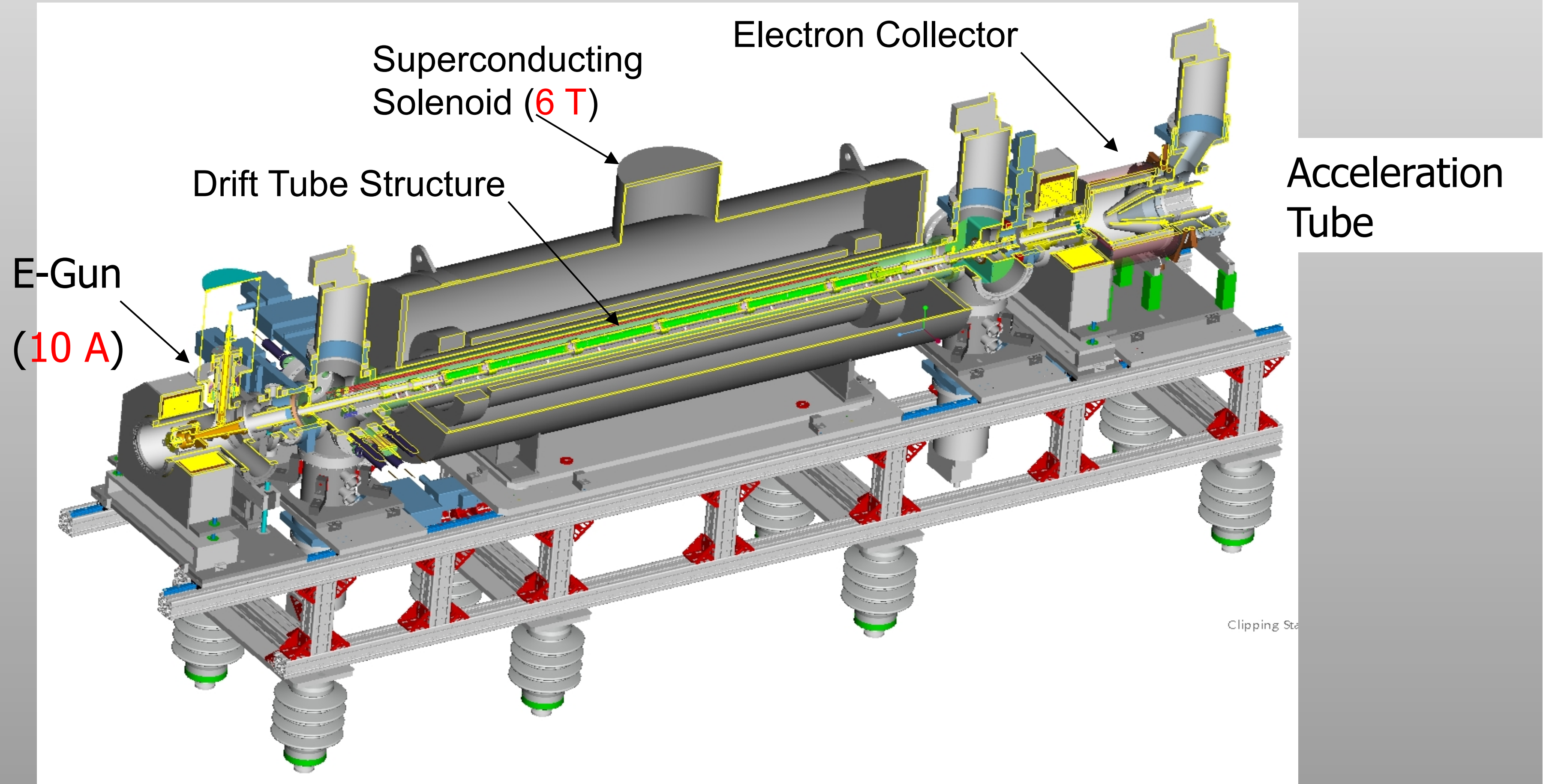


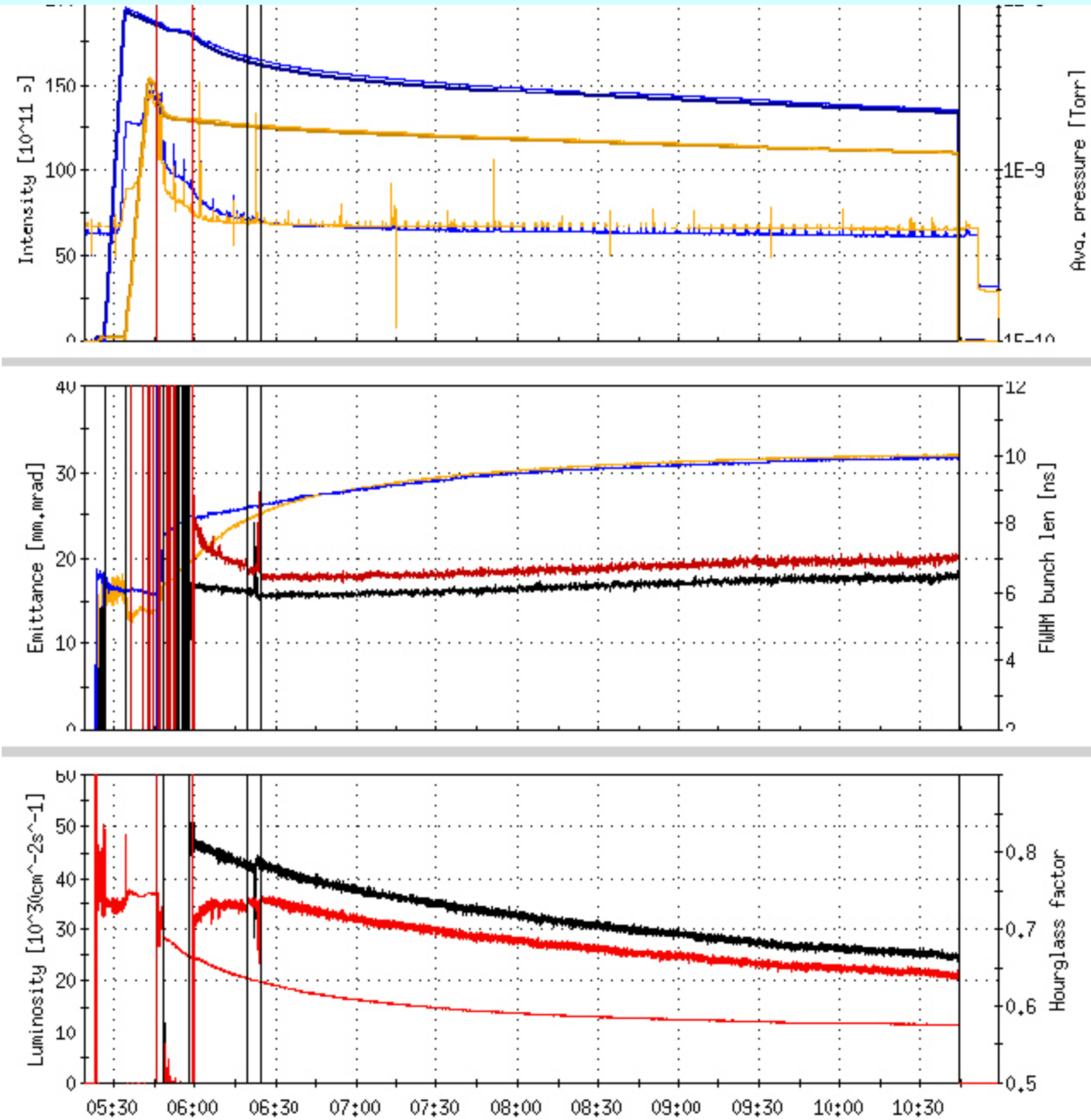
Fig. 4. Performance of the Mainz ^{3}He polarizer and compressor with the old (LNA-laser 8W, lower line) and the new (fibre-laser 30 W, upper line) laser system. The nuclear polarization is plotted versus the flux (in bar L d^{-1}).

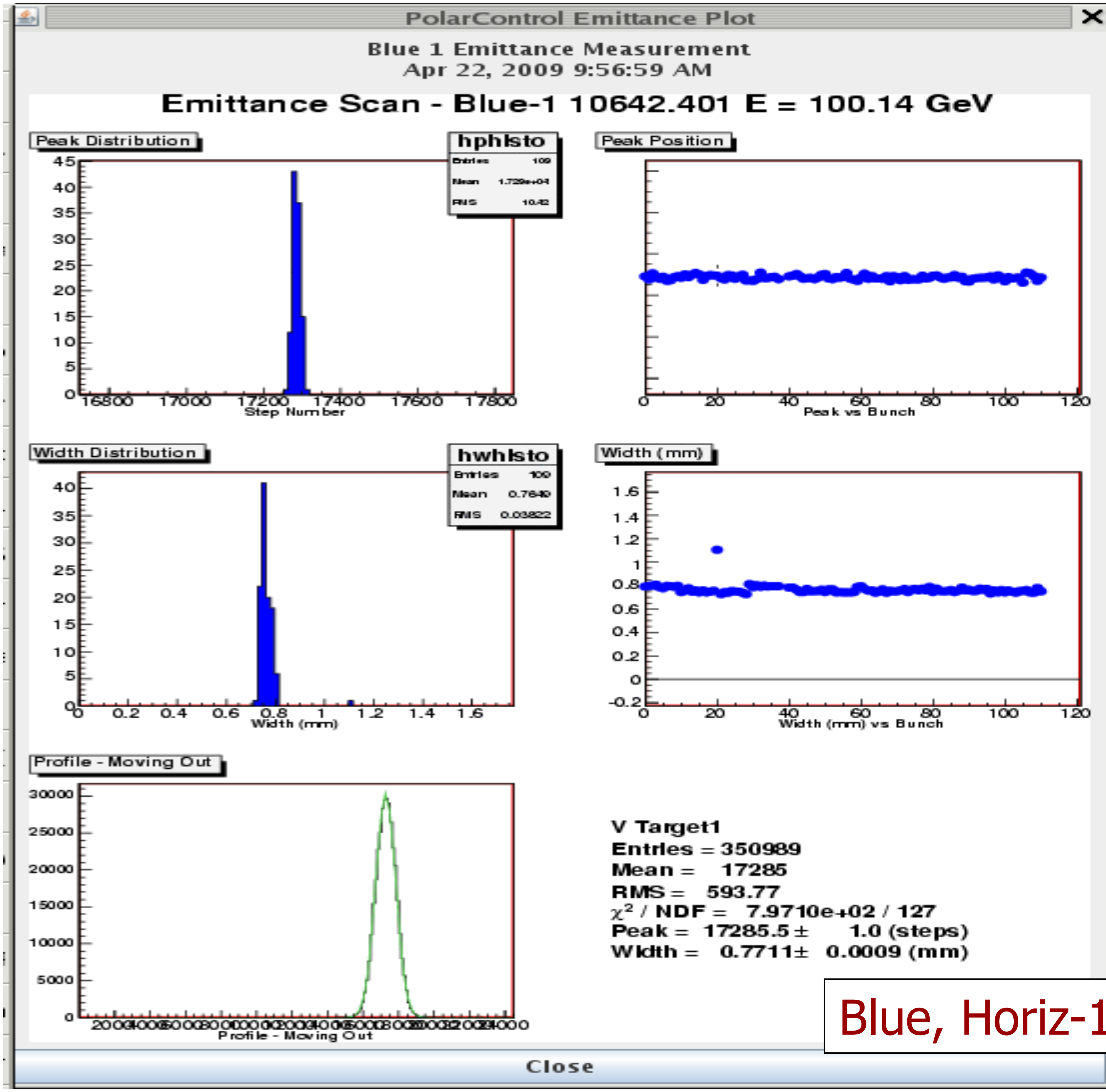
Electron Beam Ion Source at RHIC.



What intensity is expected?
EBIS Capacity is ~ 10^{12} charges/pulse
→ ~ 5 x 10^{11} ($^3He^{++}$ ions)/ per pulse.

June 24, FILL 10987, 4.75 hr, Int-0.554 pb-1, <L> = $32.4 \cdot 10^{30}$ 1/cm^2 s





Blue, Horiz-13.7pi

SUMMARY

- Small emittances out of linac. V-5pi, H-5 pi.
- Small emittances with 300 us linac pulse and about 50% scraping in Booster in BTA. V-6 pi. H- 8pi.
- Smaller beam emittances out of AGS and at injection to RHIC.
- ATR flags: V - 8pi, H - 12 pi
- CNI V -12.6pi, H - 13.7 pi
- No emittance growth during energy ramp in RHIC.
- Small emittance growth during the store.

  After 9 hrs at store: V – 15 pi, H – 13pi.

- Vernier scan ~ 16 pi, very small growth during the store time.

OPPIS upgrade with the "Fast Atomic Hydrogen Source"

- Higher polarization is expected with the fast atomic beam source due to:

  a) elimination of neutralization in residual hydrogen;
  b) better Sona-transition efficiency for the smaller ~ 1.5 cm diameter beam;
  c) use of higher ionizer field (up to 3.0 kG), while still keeping the beam emittance below 2.0 π mm·mrad, due to the smaller beam diameter.

- All these factors combined will further increase polarization in the pulsed OPPIS to:

  -*over 85% and the source intensity to 5-10 mA.*

- The ECR-source replacement with an atomic hydrogen injector will provide the high intensity and high polarization beam for polarized RHIC luminosity upgrade and for future eRHIC facilities.